# "Multi-hazard Approach for Multi-storied Buildings: A case study of Ahmedabad city"

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## Abstract

India is one of the world's most disaster prone countries. Most of the cities in the Indian subcontinent are in need of proper urban planning. It takes as long as a decade for formulation of such development plans. Hence these cities develop without any mapping of hazards to which they may be subjected to. The city of Ahmedabad is vulnerable to hazards like earthquake, fire, urban floods due to short duration high intensity rainfall, blasts etc. The city of Ahmedabad was worst affected by the earthquake of Bhuj, 2001. This study is focused on the effect of Earthquake + Fire hazard considering the pipeline network of gas and water, on the habitats of Ahmedabad city. The said combination is taken, as fire generally occurs following earthquakes which significantly shake buildings. From among various types of public and private buildings in the city, this research is exclusively based on the study of the effect of earthquake on Government Multi Storied Buildings, as the data required for the research is available in the public domain. Data related to the various external parameters of earthquake like Soil Profile, Water Table, Shear Velocity, N – Value, Zoning Regulation, Fault line, Lineaments etc. are collected from various localities of Ahmedabad. This data is fed into Geographical Information System (GIS) and various maps are generated related to the parameters mentioned above. These parameters are applied on pre identified 76 Government multi storied buildings (study buildings) within the city in GIS Environment. Only those (5) multi-storied government sample buildings that are found vulnerable to earthquake hazard are further analysed for hazard of fire. A fire hazard map is formulated based on similar line based on the parameters affecting fire. Specific details of the buildings under study are also collected for the hazard of earthquake and fire by a survey. Based on experience and consultation with experts, professionals and academicians risk has been calculated for these parameters. Risk assessment is done and population at risk is calculatedfor all these sample buildings. Finally guidelines are formulated based on the study of the existing practices of the local body (corporation) for construction of new multi-storied buildings. Maps formulated for earthquake and fire together with the guidelines (check list) will be very useful for local authorities from the safety point of view.

**KEYWORDS***:* Geographic Information System (GIS)[1], Earthquake[2], Fire[3], Multi-storied building[4]

- **Introduction**

Urban habitats are exposed to various hazards like earthquake, floods, fire and landslides if located in mountainous region. Earthquake, flood and landslide are natural hazard but fire can be natural or manmade. Sources of urban fire are LPG cylinders, CNG pipelines, Petrol Pumps, Chemical Factories, Paper Industries, Electric Short Circuit and Power Stations/Substations. For fire followed by earthquakes in multi-storied buildings, sources of fire due to LPG

cylinders, CNG pipelines and short circuit are of more concern. Historic record shows that fire is generally triggered after earthquake causing after damages to oil and gas pipelines, electrical transmission lines. Multi-storied buildings in India are designed for hazards like earthquake; cyclone etc. in isolation but a hazard like earthquake is followed by another hazard like fire. The behaviour of the building changes due to this and it leads to premature failure. The percentage of number of non-engineered (nonstandard materials and low construction quality standards) structures is almost 80% in developing countries like India, and almost 50% of the current structures under construction does not follow building codes (Government of India 1998). Poor construction quality and poor quality materials used for construction increases the vulnerability of the building to hazards or a disaster waiting to happen. A Multi-hazard approach shall therefore be adopted for design of buildings to reduce population at risk to minimum.

China, India and Bangladesh have the maximum number of deaths occurring each year from natural disasters in Asia (Office for the Coordination of Humanitarian Affairs 2009). The countries of India and Bangladesh are pestered with cyclones and floods every year which leads to the deaths of a large number of people and other direct and indirect losses. According to Resource Management Strategies Inc. (RMSI), in India, the limited availability of data from past losses makes it difficult to estimate risk and potential losses from hazards of the future. The data that is available is sparse and is not easily accessible. The Vulnerability Atlas of India includes hazard maps and has been successful in helping individuals to take action to reduce risk through land use planning (RMSI 2009).

- **Objectives**
  1. To study the effect of multi hazards i.e. earthquake and fire on public multi-storied buildings.
  2. Formulation of multi hazard map using Geographic Information System (GIS)
  3. To study the existing practice followed by local body and formulate a check list for existing limitations and disparity in development for multi-storied buildings.
  4. Formulation of guidelines for practicing engineers and formulating road map for setting safety standard.

- **Scope of Research Work**
  1. Multi-storied public buildings of Ahmedabad city are taken as case study.
  2. To create GIS maps for soil properties (including N – value and Vs), underground pipelines of water and gas, ground water table, fault lines
  3. Study and comment on design features for earthquake resistance and fire safety measures of selected buildings.

- **Research Question**
  1. Do we have any Multi-hazard map for the city of Ahmedabad?
  2. Are the multi-storied buildings in India safe from the effect of multi-hazards such as earthquake and fire?
  3. Do we have any mitigation strategies for multi-hazards?

- **Methodology of Research**

A primary survey has been conducted within the city limits of Ahmedabad City wherein data is collected for desired parameters of Earthquake hazard. Respective Maps have also been formulated in Geographical Information System (GIS) and Remote Sensing (RS) Environment. Here qualitative information is converted into quantitative based on experience and consultation with professionals, academicians and experts of the subject and a table of values, is formulated.The methodology adopted is not experimental and techniques adopted are both qualitative and quantitative.

- **Data Collection and Analysis**

The research study is based on Multi storied Government Buildings within the limits of Ahmedabad city. The total population of the city is more than 45 lacs. In present research work, the effect of earthquake is taken as the basic hazard and multi storied buildings vulnerable to EQ are identified. For identifying multi-storied public buildings within the city, Property Tax Department of Ahmedabad Municipal Corporation (AMC) was consulted and data related to all the public buildings was collected. This information from tax department is considered to be authentic and meticulous as physical survey is conducted once in 3 – 4 years for assessment of buildings. These tax bills give us information regarding the occupancy of building, built-up area, usage of building and age of building. From among all the non-residential buildings of the city, data has been scrutinized and sorted for Government Buildings. Further out of about 622 Government Buildings, the research is narrowed to the multi-storied Government Buildings which are 76 in number (study buildings). Various government multi-storied buildings were identified by field survey and location information is gathered by using a GPS system. This data is fed into GIS and a map is generated based on their coordinates and thus location of all these 76 buildings is marked. The vulnerability of multi-storied buildings for hazard of earthquake depends on various internal as well as external parameters. Here internal refers to the planning aspects, design criteria, construction techniques and materials used during construction of building whereas external parameters include those that depend on the location of the building and are beyond the control of civil engineer. These external parameters include Soil Profile, Ground Water Table, N – Value, Shear Velocity (Vs), Fault Line, Lineaments, Zoning Regulation etc. for identification of vulnerable buildings for earthquake hazard. Generally planning aspects, design criteria, construction techniques and construction materials to be used for a particular building also depend on these external parameters. The present research work is carried out considering both internal as well as external parameters for hazard of earthquake as both are equally important for risk assessment. Apart from this, underground utilities like pipelines for water and those for CNG gas are also assessed for the entire city. The bursting of water pipeline during an earthquake can affect the soil and may ultimately lead to differential settlement and structural and non-structural failure. During an event of fire, bursting of water pipeline may reduce pressure of water in pipes and water required in building for active fire suppression may not serve the purpose. Bursting of CNG pipelines in vicinity of multi-storied building may interrupt the rescue operations and increases the vulnerability of the building for fire followed by earthquake. *Figure – 1* shows the methodology adopted for analysis in GIS for mapping earthquake hazard.

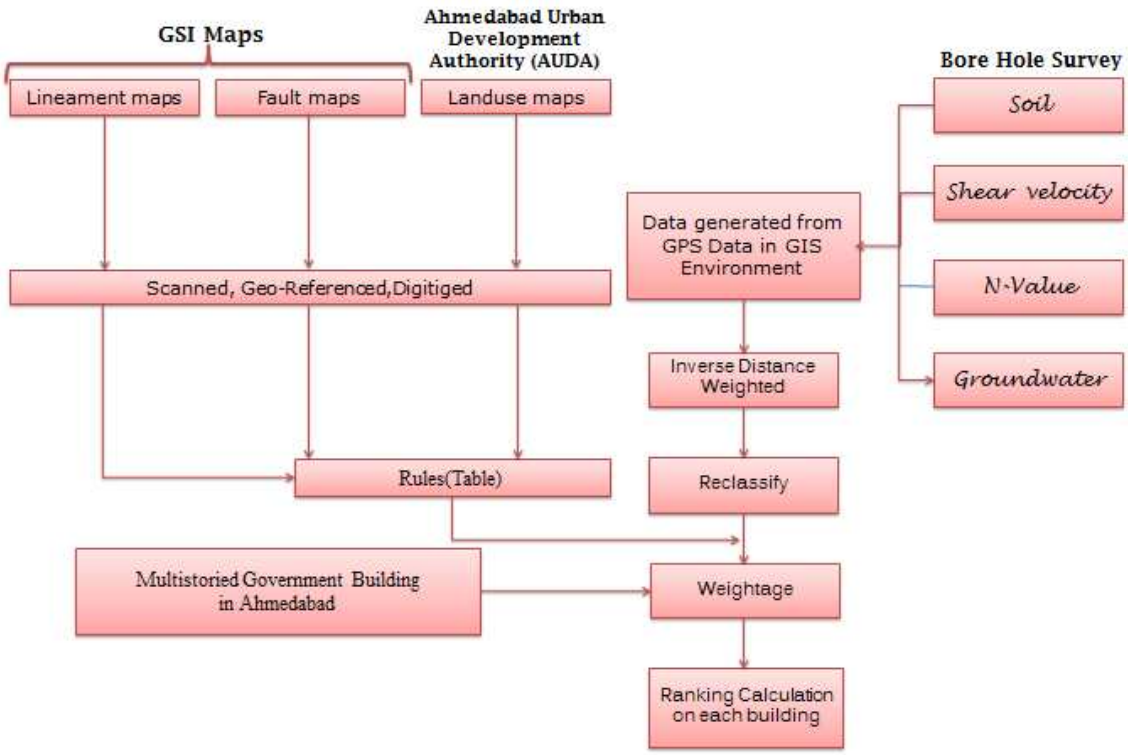


***Fig. – 1:*** **Methodology adopted for formulation of map for EQ Hazard**

- **Interpretation**

The city of Ahmedabad is spread in the area of 460 sq. km., Initially it was thought of to have the borehole and collect soil samples from 1 sq. km. each but as the corporation limit has extended recently and most of the outskirts area though in residential /commercial zone are yet agricultural land, the data collection was restricted to the old city limit of 2011. Hence in order to get the details of soil profile, ground water table, standard penetration value (N – value) and shear velocity ($v_s$), borehole details at 140 random locations are collected for further technical analysis. These data for soil profile are collected from various soil testing laboratories of the city. The locations of these boreholes are evenly distributed within the length and width of the city. With the help of these locational details, intermediate values are calculated by Inverse Distance Weight (IDW) method in GIS. This is one of the most effective methods for finding out intermediate values when data available is more.

For Fault lines and lineaments existing within the city, map from Geological Survey of India (GSI) is collected and buffers are created taking into consideration the maximum radius of 225 m and 100 m respectively. These buffers are created, based on the experience and historic data considering the severity of damage to buildings from centre line of fault lines and lineaments. The zoning regulation of the city has been depicted by different colour combination. Here buildings located in commercial zone are considered to be in worst condition as during office time, these buildings are densely populated with both people working and visiting the premises.

The risk ranking and weightage has been given based on historic records, experience and in consultation with working professionals, academicians and subject experts. Based on the parameters discussed above, for earthquake hazard and weightage assigned to various parameters as mentioned in Table – 1 below, all the government multi storied buildings are analysed and risk ranking values are calculated. The detailed calculation for various buildings is as per the Annexure – I attached.

**Table – 1: Risk Prioritization based on various parameters**

| Parameters | Risk Ranking | | | |
|---|---|---|---|---|
| | **A = Weightage 20** | **B = Weightage 15** | **C = Weightage 10** | **D = Weightage 5** |
| N- value | 1 - 8.0 | 8.1 - 15.0 | 15.1 - 22.0 | > 22.0 |
| Type of soil | CI / MI | CL / ML | SM | SC |
| Ground water Table (m) | 1 - 8.0 | 8.1 - 12.0 | 12.1 - 18.0 | > 18.0 |
| Shear Velocity Vs (m/sec) | 139.0 - 173.5 | 173.6 - 208.0 | 208.1 - 242.6 | > 242.6 |
| Land use Regulation (AUDA Propose Zoning) | Industrial Zone (General/Special) | Core walled City/Central Business District | Residential Zone(1/2/3) | Others |
| Distance Regulation for Faults (m) | Within 150.0 m radius | Between 150.1-200.0 m | Between 200.1-225.0 m | > 225.0 m |
| Distance Regulation for Lineaments (m) | Within 50.0 m radius | Between 50.1 - 75.0 m | Between 75.1 - 100.0 m | > 100.0 m |

Here A = Extremely High Risk, B = High Risk, C = Moderate Risk and D = Low Risk

For each of these buildings, a further detailed survey is conducted to identify the building elements at risk considering parameters like Number of storeys, height of each storey, type of structure, type of wall (brick/rcc), type of building, type of soil, provision of shear walls, type of foundation, type of building material used, cracks visible on building (structural/non- structural), age of building, type of structure & planning aspects and no. of potential users of building. This building specific data is a very effective rapid visual screening tool for risk assessment of particular building. It also depicts the condition of the building and is useful in formulating guidelines for planning new buildings. It is noted that most of these buildings had minor non-structural and no structural cracks during the devastating earthquake of Gujarat (Bhuj) – 2001.

Based on the table formulated for different parameters for earthquake hazard, Risk calculations are made for the 76 pre-identified study buildings. Out of these 76 study buildings, risk ranking of 5 buildings is found to be 90 or more. These 5 multi-storied buildings are identified as more vulnerable to earthquake hazard compared to other pre-identified study buildings. Hence these 5 buildings are studied for further analysis of fire hazard and are considered as sample buildings. For analysis of buildings for fire hazard, earthquake hazard is taken as base hazard and assessment of these sample

buildings considering various parameters of fire is done. Thus from 76 study buildings, 5 sample buildings are assessed for the hazard of fire.

For assessing the sample buildings for fire hazard, following parameters are studied.

1. Historic data of last 6 years of the entire city related to the events of fire.
2. Zoning regulations of local development authority
3. Gas pipe line details and network of the entire city
4. Water distribution network system of the entire city
5. Locations of the nearest fire stations, petrol pumps and CNG filling stations
6. Population density of the area along with household units
7. Location of the Industrial areas which are more vulnerable (GIDC)
8. Road Network

Based on the above parameters, fire hazard maps are generated in GIS environment. All the primary manual data collected are digitised based on the geo-reference coordinates. Historic data for fire calls in a given locality is studied and sorted ward-wise based on the area delimited by Municipal Corporation. This data is further converted into point file and then geo-referenced to find their exact location. Zoning guideline of the city is predefined and a given multi-storied building is to be planned in accordance to this guideline only. These zoning regulations cannot be altered. In the city of Ahmedabad, PNG pipelines are laid throughout the city and residents avail this facility for domestic use. In normal course, as PNG is lighter than air, it dissipates in the air quickly but can ignite fire. For the locality where PNG pipelines have not yet been laid, end users use LPG cylinders. LPG is heavier than air and so during leakage it gets accumulated and hardly dissipates. So this may cause fire and at times it may act as bomb also if cylinder bursts.

Water distribution pipeline network system of Municipal Corporation is also collected as during an earthquake hazard, if there is bursting of trunk main or any of its subsidiary pipe, it may lead to seepage pressure in upward direction for a given building. This may further lead to liquefaction depending upon soil condition and may lead to differential settlement and can develop structural cracks. To counteract this effect, water pipeline network is also considered. The entire data collected from local authority is digitised, geo-referenced for exact location. Location of hazardous industries, petrol pumps and CNG filling stations are also mapped as its proximity to multi-storied building may increase its vulnerability. Fire station locations and road proximity of a given building are also mapped for passive fire suppression. From the Census Department, Government of India, data regarding the population, house hold units and area of every ward is collected. Population density and household density is further calculated to study the population which can be affected during earthquake and fire hazard. For the parameters mentioned above, different maps are formulated in GIS environment for fire hazard.

Location of these 5 sample buildingsare then superimposed for analysis for the hazard of fire. For all these sample buildings, a buffer is generated of 1 kM radius with a given multi-storied building as centre point. The effect of all the above mentioned parameters are superimposed and risk assessment of each of the sample building is done. Table – 2 shows vulnerability index for given sample building.

***Table – 2*: Risk category for analysis of Buildings based on different parameters**

| Parameters | High Risk | Moderate Risk | Low Risk |
|---|---|---|---|
| Gas Pipe line Area & Water Trunk main Area | ≥ 50% | 49.9 % - 25 % | < 25% |
| Population | ≥ 50000 | 49999 - 25000 | < 25000 |
| Household | ≥ 20000 | 19999 - 10000 | <10000 |
| Historical Incident data (Fire Calls) | ≥ 100 | 99 - 50 | < 50 |
| River | < 10% | 10 % - 19.9 % | ≥ 20% |
| Road Connectivity | Approach Road | Other District Road | MDR |
| Fire Station | ≥ 8.0 KM | 4 - 7.9 KM | < 4. 0 KM |
| GIDC / Major Industries | Building within GIDC | Outskirts GIDC | ≥ 1.0 KM from GIDC |

***Table – 3*: Risk Ranking of Study Buildings based on different parameters**

| Sr. No | Name | Total Area (Ha) | Gas pipe area (Ha) | Water Pipe Area (Ha) | Total Area (Ha) | Population | Historical Data (Fire Calls) | House hold units | Water Body (River/Pond/Lake) % | Gas/ Water Area % | Ward Area(Ha.) | Factor | Pop. Distn | H.H._Distn | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L.G Hospital Hostel Building | 314 | 52 | 80 | 132 | 95000 | 100 | 22000 | 7 | 42 | 279 | 113 | 106918 | 24760 | 2 |
| 2 | M.S Building | 314 | 43 | 0 | 43 | 77000 | 150 | 14000 | 0 | 14 | 1265 | 25 | 19113 | 3475 | 4 |
| 3 | Bachat Bhavan | 314 | 0 | 66 | 66 | 60000 | 80 | 12000 | 17 | 21 | 209 | 150 | 90144 | 18029 | 3 |
| 4 | Sales Tax Bhavan | 314 | 48 | 51 | 99 | 50000 | 80 | 10000 | 21 | 32 | 716 | 44 | 21927 | 4385 | 5 |
| 5 | Apna Bazar | 314 | 0 | 70 | 70 | 110340 | 78 | 13552 | 20 | 22 | 212 | 148 | 163428 | 20072 | 1 |

Various building specific parameters that are also studied for analysis of fire hazard are Height of Each Floor, Approach to Road, Distance of Building from Fire Station, Distance between adjacent Buildings, Availability of Open Space, No. of Exit

in Given Building, Provision of Fire Safety, Fire Fighting Equipment's Installed, Provision of Pantry/ Kitchen, Fuel used in Pantry with type of fuel Used, Gas Pipelines in Vicinity, Population in vicinity likely to be affected and No. of Potential Users of Building. Finally population at risk is calculated for all these sample buildings based on vulnerability assessment.

**Conclusion**

The concept of Multi-hazard is new in Indian context. But this practice of Multi-hazard has to be adopted as historic data shows that a single hazard never comes in isolation but it is always accompanied or followed by other hazards. Under this condition if still we design the multi-storied buildings for single hazard in isolation, then these buildings would be vulnerable and population would be exposed to high risk. Thus it is high time for India shall to formulate Multi-hazard maps for cities to minimise the risk and fatality.

Practice followed in India for designing multi-storied buildings is considering earthquake or wind hazard and assessing various load combinations as suggested in IS: 875 – 1987 (Part I, II, III), IS: 1893 – 2002, IS: 456 – 2002, IS: 13920 – 1993 but we shall consider fire also during the planning phase of multi-storied building for a case in which load combination for earthquake is design criteria.

Depending on the local and regional parameters, multi-hazard maps shall be generated for metro cities by local bodies and awareness shall be created among local professionals regarding the importance of multi-hazards, by capacity building programs and regional workshops.

Multi-hazard map formulated for the city of Ahmedabad can be used by local authorities by just mentioning latitude and longitude of the said location where the building is to be constructed, in GIS. Once this is done, all the mentioned external parameters for the hazard of earthquake and fire can be assessed immediately. Whether the said building is vulnerable to the hazard of earthquake + fire can be known and design criteria can be selected.

Performance based design criteria shall be adopted for multi-storied buildings. This concept is very common in developed countries like US, Europe etc. particularly for hazards like earthquake + fire.

For design of any new multi-storied building, a team is to be formed consisting of Architect, Structural Engineer, Electrical Engineer, Mechanical Engineer and Fire Safety Engineer. In case if the building is to be constructed in GIDC or in vicinity of hazardous industry, then Chemical Engineer shall also be included in the team. Any modification or alteration shall not be allowed in the building without the prior approval of all of these team members.

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